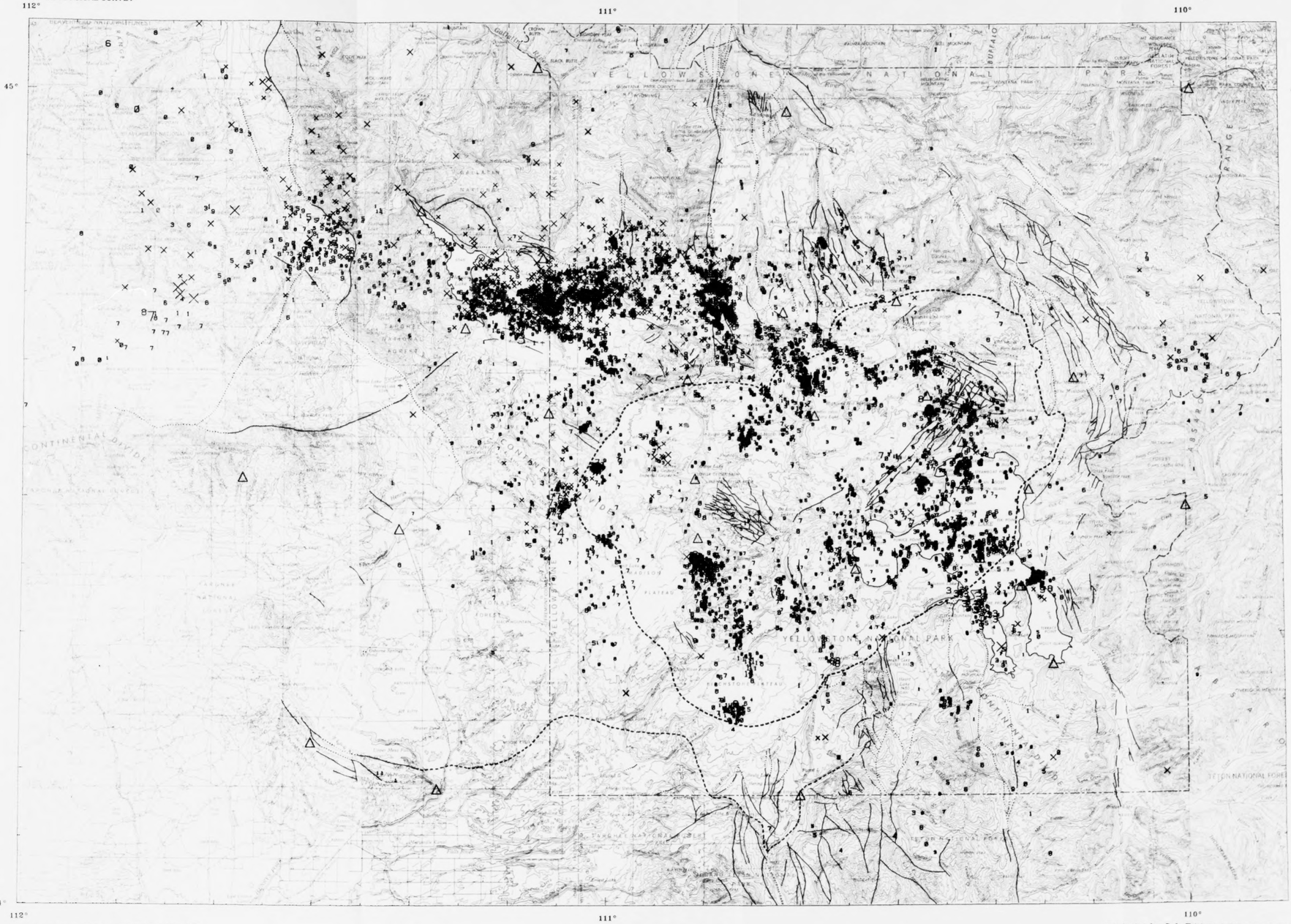
DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MISCELLANEOUS FIELD STUDIES
MAP MF—2022



Base from U. S. Geological Survey topographic maps, Ashton-1967, Billings-1962, Bozeman-1967, Cody-1962.

SCALE 1:250 000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 30 KILOMETERS

CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

TRUE NORTH
MAGNETIC NORTH
APPROXIMATE MEAN DECLINATION, 1988

AREA OF MAP

MAP 1—EPICENTERS, YEAR OF OCCURRENCE, AND MAGNITUDE

EXPLANATION FOR MAP 1

X — Epicenter of earthquake that occurred between January, 1964, and December, 1972

3,4,5,6,7 8,9,0,1 — Epicenter of earthquake that occurred between January, 1973, and December, 1981; number indicates year of occurrence

Note: symbol size indicates magnitude range of earthquake

MAGNITUDES

- 0.00 - 0.99 magnitude
- 1.00 - 1.99 magnitude
- 2.00 - 2.99 magnitude
- 3.00 - 3.99 magnitude
- 4.00 and greater magnitude

Seismograph station in operation two or more years

Fault (dotted where concealed) showing evidence of Quaternary movement

Buried caldera boundary fault

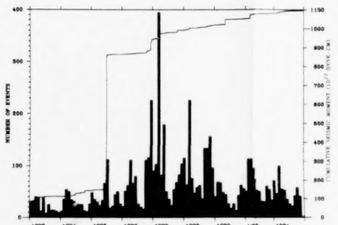


Figure 1.–Level of seismicity (bars 1/12 year wide) and strain release (line) variation with time, Yellowstone National Park area. Strain release is as seismic moment (M_o) computed from magnitude (M_L) using the relationship $\log M_o = 1.4M_L + 17.0$ (Wyss and Brune, 1968).

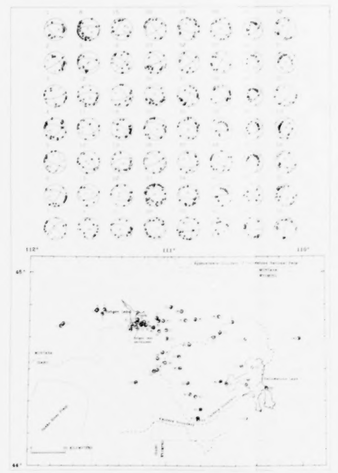


Figure 2.–Earthquake focal mechanisms; lower hemisphere projection, dots indicate compressions, circles indicate dilatations. T and P indicate tension and compression axis. Mechanism numbers correspond to numbered circles on map.

Fault locations from R. L. Christiansen (written communication, 1980, 1988) and U. S. Geological Survey, 1972.

INTRODUCTION

The earthquake activity in the Yellowstone region is part of a belt of seismicity extending from southern Utah to northwestern Montana. The 1959 magnitude 7.3 Hebgen Lake earthquake is the largest historical event along this trend. Yellowstone National Park is also the focus of extensive Quaternary volcanic activity that relates to a long lived volcanic system that has progressed from southwest to northeast along the trend of the Snake River Plain, ending in a 40 by 70 km caldera formed in a volcanic eruption 600,000 years ago. Thus the seismicity shown on these maps is part of a major tectonic feature of western North America and may also be influenced by or influence the volcanic processes occurring in the region. A more complete description of the geology and geophysics of the Yellowstone region can be found in Smith and Christiansen (1980), Christiansen (1984), and Smith and Braile (1984).

The seismicity displayed on these maps occurred over a 17 year period and was recorded at a variety of seismograph stations, which has resulted in much variation in the reliability and completeness of the data set. The earthquake epicenter data are presented on 2 maps. Symbols on map 1 identify events by year of occurrence with the symbol size indicating the magnitude range. Symbols on map 2 indicate the reliability of the earthquake epicenters. Variations in the level of seismicity and strain release with time are shown (Fig. 1), as well as earthquake focal-depth cross sections and representative earthquake focal mechanisms (Fig. 2).

NETWORK HISTORY

In 1963, the U.S. Geological Survey (USGS), at the request of personnel from Yellowstone National Park (YNP), began to operate seismograph stations in the Yellowstone-Hebgen Lake region. The operating conditions were difficult for the instrumentation available at that time. Each station had to operate independently, requiring a dark room for photographic recording, chronometer, radio time-code receiver, and 110 volt power with battery backup for periods of power failure. Stations in the interior of YNP had to operate up to 30 days without servicing during the winter. By late 1963, stations were operating in YNP at Mammoth Hot Springs and Canyon Village. By late 1964, five stations were recording earthquake activity in YNP and the Hebgen Lake area to the west. This network monitored the level of seismic activity in the region till 1972 but instrument problems limited the number of events recorded on three or more stations to about 350 earthquakes. Earthquakes in the Yellowstone region with magnitudes (M) greater than 3.5 were often recorded by other seismograph stations in the western United States. These data were reported to the International Seismological Center (ISC). The ISC data have been combined with the locally recorded data to produce a data set of 775 Yellowstone region earthquakes that is nearly complete for M 4 and larger events from 1964 to 1972. In November 1972, the network was modernized with the installation of battery-powered stations from which the data were telemetered by radio and telephone line to Mammoth Hot Springs, YNP, where they were recorded on a common time base. After 1979, the data were telemetered to the USGS in Menlo Park, California. In November 1981 the network was reduced to two stations recorded at Mammoth Hot Springs and Old Faithful. In November 1983, the network was reactivated with data from 16 stations being telemetered to the University of Utah (UU) at Salt Lake City, Utah, for analysis.

The 1971 network consisted of eight stations in YNP and four in the Hebgen Lake area. In October 1974, the network was enlarged, both by increasing the density of stations within YNP and by extending the network beyond the park. This network consisted of 26 stations. The network was reduced by nine stations in 1976, increased by four stations in 1978, and reduced by five stations in 1980. Three sites were occupied from 1964 onward and 8 sites were occupied from 1971 to 1981. The long-term network was supplemented with data from temporary stations operated by the USGS and the UU and from long-term stations operated by the University of Montana, Montana Bureau of Mines, Idaho National Engineering Laboratory (INEL), and Ricks College, Rexburg, Idaho. The INEL and Ricks college data were used extensively from 1978 onward and greatly improved the quality of earthquake locations in southwest YNP. A catalog of the hypocenter data for the earthquakes from 1973 to 1981 (6,349 events) along with more details on the network and data processing is available (Pitt, 1987).

DATA COMPLETENESS AND RELIABILITY

From 1964 to 1972, the number of earthquakes that could be located was usually determined by the number of seismograph stations in operation. From 1973 onward, the number of stations in operation was usually adequate, and the manpower available for data analysis generally determined which events were chosen or excluded for hypocenter determination. The number of earthquakes located in intervals of 1/12 year and the cumulative energy release (seismic moments) from 1973 to 1981 are shown on figure 1. The moment curve is dominated by a magnitude 6 earthquake in June 1975 even though the number of processed aftershocks for this event is less than for smaller events occurring in later years when the data processing was more complete. The data for the years 1976, 1977, 1978, and 1981 are the most complete of the nine year period; 1973 and 1974 the least complete.

The earthquake hypocenters were determined with the program HYPO71 (Lee and Lahr, 1975). HYPO71 gives the earthquake coordinates, focal depth and magnitude along with the root mean square of the residuals of the solution (RMS), number and distribution of stations, and standard errors in horizontal (ERH) and vertical (ERZ) position. These values can be used to estimate the reliability of the earthquake locations. The input data and hypocenter output parameters for all events were examined and each event was assigned to one of four epicenter uncertainty groups. This classification was somewhat subjective. Epicenters are most accurate in the parts of the network well covered by seismograph stations and where the velocity model is most realistic. The primary bases for assignment to a particular class was the distribution of stations about the earthquake epicenter and the number and quality of observations. Other criteria such as the RMS, ERH, or the reliability of the velocity model in the area of the event were secondary considerations. The uncertainty values are intended to be used to evaluate the geologic significance of earthquake trends. For example, a 5 km long alignment of events with a one km uncertainty may be interpreted as a possible fault 5 km in length. If the epicenters were of greater uncertainty, the alignment might only reflect scatter due to inadequate data.

CROSS SECTIONS

Cross sections showing variation in earthquake focal depths across the region are shown beside map 2. The plotted earthquakes are restricted to events with 1 km epicenter uncertainty which also have a HYPO71 ERZ of 2 km or less. Section A-A' extends from the Hebgen Lake area southeastward across the edge of the caldera. Section F-F' covers the approximate area enclosed by the ring fracture zone (source of the last major volcanic eruption 600,000 years ago) within the caldera. Sections B-B', C-C', D-D', and E-E' show variations at right angles along the length of section A-A'.

EARTHQUAKE FOCAL MECHANISMS

A selection of focal mechanisms from various areas on the map is shown in figure 2. The mechanisms are for single earthquakes, they are ordered by longitude from west to east in two groups. The first group extends from near the west edge of the map through the epicentral region of the 1959 Hebgen Lake earthquake, eastward to include the seismicity north of the Yellowstone caldera. The second group begins west of the caldera and includes events within, south, and east of the caldera. Generally, events in the first group have better focal-depth control than events in the second group.

DISCUSSION

The cumulative moment and numbers time graphs (fig. 1) show the sporadic nature of the seismicity. Earthquakes frequently occur in swarms lasting from less than an hour to several weeks. Swarms within the calderas generally are shorter in duration and more intense in rate of activity than those outside the caldera. This difference may be due to the influence on intracaldera swarms of fluid flow associated with hydrothermal systems which could cause a rapid decapation of seismic strain. The bursts of activity in June and July 1975 and March 1977 are better described as mainshock aftershock sequences rather than swarms.

The seismicity for the period 1964 to 1981 appears to be a combination of long term after-shock activity from the 1959 Hebgen Lake earthquake and of broader scale regional tectonic activity. The earthquake epicenters tend to concentrate in clusters up to 5 km maximum dimension. These clusters may define larger trends such as an eastward trend in the Hebgen Lake region or northward trends in the southwestern and northeastern parts of the caldera. Some epicentral trends appear to be related to mapped faults but many do not. The faults associated with the activity in the southwestern part of the caldera may be harmed beneath the young volcanics in the area.

The only earthquakes with focal depths below 10 km are in the Hebgen Lake area, and their depths decrease northward (section B-B'). Modeling of the surface displacements of the Hebgen Lake earthquake (Barrientos and others, 1987) indicate the event occurred on two subparallel, southwest dipping planes approximately coincident with this seismicity. The plotted epicenter of the Hebgen Lake earthquake (Map 2, Fig. 2) was determined by J. W. Dewey (written communication, 1986) using the June 1975 magnitude 6 earthquake as a calibration event. Eastward from Hebgen Lake along section A-A' focal depths do not exceed 10 km and shallow to less than 5 km within the caldera. The influence of the heat from a possible magma chamber beneath the caldera may be responsible for the lack of earthquakes deeper than 5 km (section E-E').

The earthquake focal mechanisms show a mix of strike-slip and normal faulting with a few thrust fault mechanisms (fig. 2, nos. 43, 45, and 46). Tension axis of the normal and strike slip solutions vary considerably though a northeast-southwest orientation is most common. The least and intermediate principle stresses across the region may be similar in magnitude, resulting in earthquakes occurring on previously existing faults of varying orientations. Mechanisms in the 1959 Hebgen Lake earthquake aftershock zone (fig. 2, nos. 7 to 15) have large tension axis variations between closely spaced events (fig. 2, nos. 13 and 14 for example). This may indicate a region of localized inhomogeneous stress patterns produced by the large event.

REFERENCES CITED

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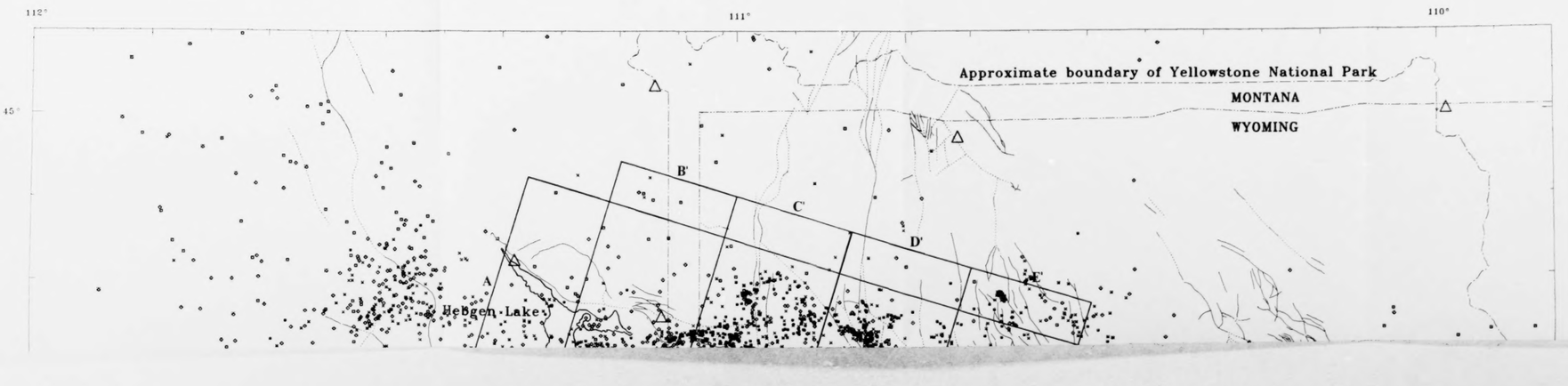

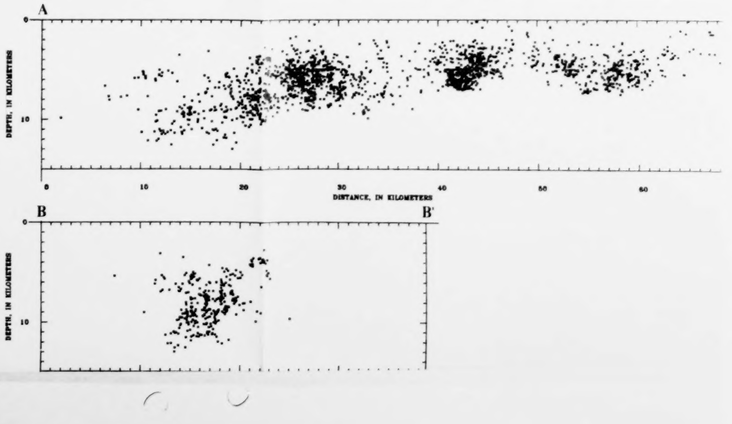

111°

110°

45°

44°

EXPLANATION FOR MAP 1

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- 3,4,5,6,7 8,9,0,1 — Epicenter of earthquake that occurred between January, 1973, and December, 1981; number indicates year of occurrence

Note: symbol size indicates magnitude range of earthquake

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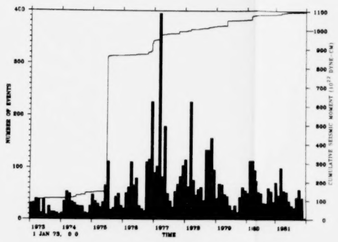

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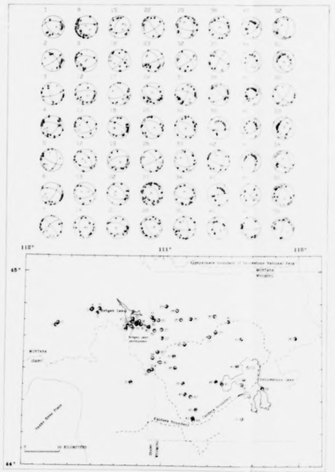

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5 0 5 10 15 20 MILES

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APPROXIMATE MEAN DECLINATION, 1968

AREA OF MAP

MAP 1—EPICENTERS, YEAR OF OCCURRENCE, AND MAGNITUDE

INTRODUCTION

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111°

110°

45°

Approximate boundary of Yellowstone National Park

MONTANA

WYOMING

A

A'

B

B'

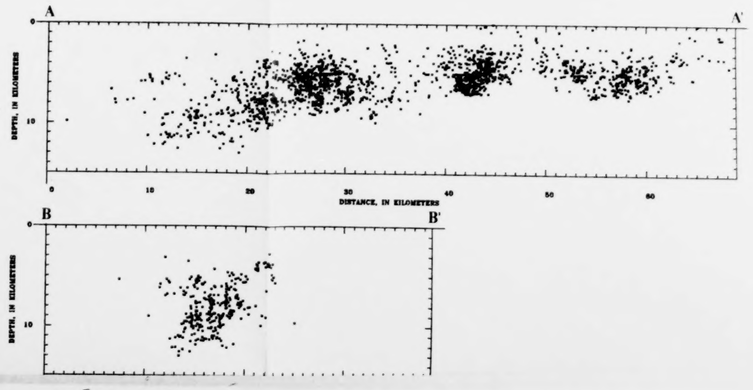
C

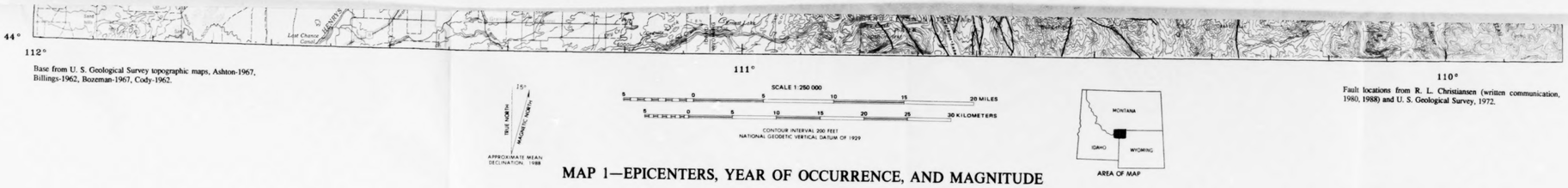
C'

D

D'

Hebgen Lake





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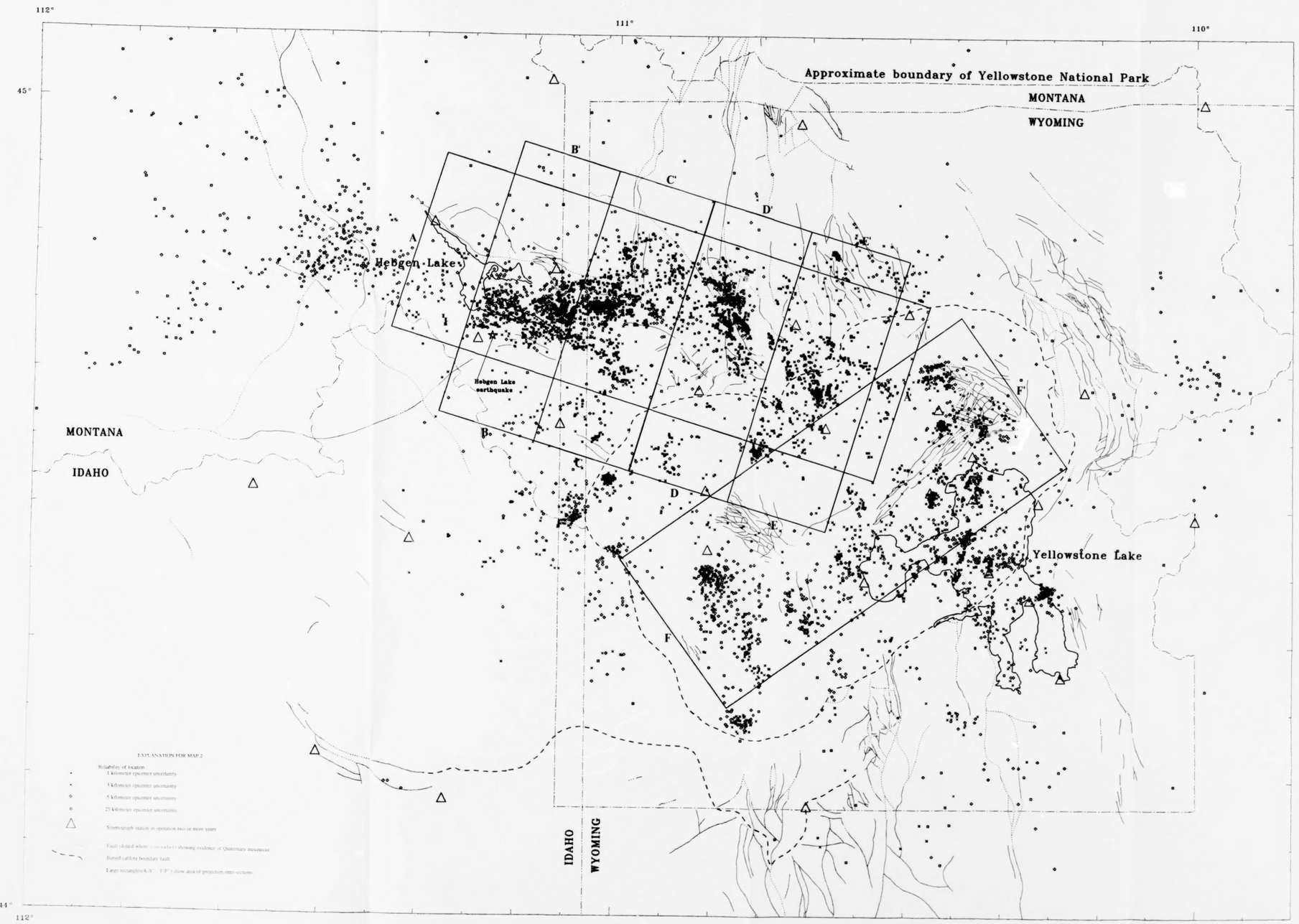
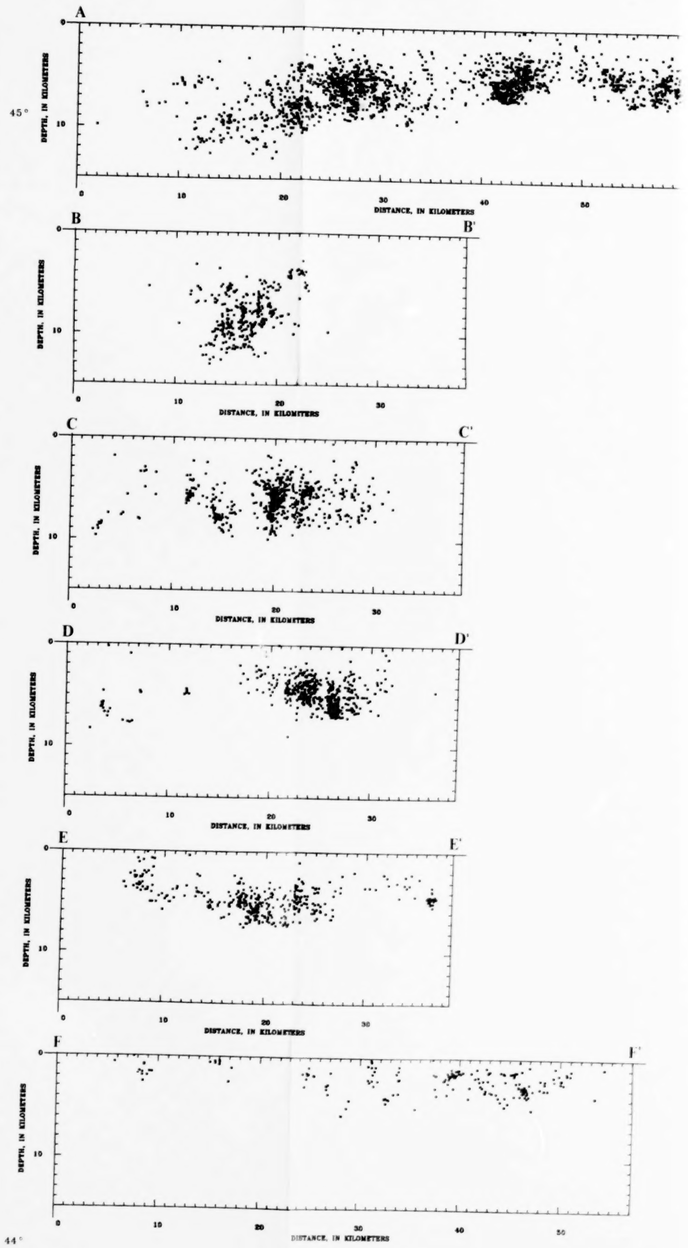
Wyss, M., and Brune, J. N., 1968, Seismic moment, stress, and source dime... the California-Nevada region. Jour. Geoph. Res., v. 73, no. 14, p. 4681

Figure 2.—Earthquake focal mechanisms; lower hemisphere projection, dots indicate compressions, circles indicate dilatations. T and P indicate tension and compression axis. Mechanism numbers correspond to numbered circles on map.

MAP 1—EPICENTERS, YEAR OF OCCURRENCE, AND MAGNITUDE



AREA OF MAP



Earthquakes with epicentral uncertainties of 1 kilometer and focal depth uncertainties of 2 kilometers are projected onto a vertical plane in section. See map 2 for area of projections.

Manuscript approved for publication, October 15, 1987

MAP 2—EPICENTERS, RELIABILITY OF LOCATION, AND AREA OF CROSS SECTIONS

MAPS SHOWING EARTHQUAKE EPICENTERS (1964–81) IN YELLOWSTONE NATIONAL PARK AND VICINITY, WYOMING, IDAHO, AND MONTANA

By

A.M. Pitt

1989

y topographic maps, Ashton-1967,
dy-1962.

111°

110°

44°

SCALE 1:250 000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 30 KILOMETERS

CONTOUR INTERVAL 200 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

APPROXIMATE MEAN DECLINATION, 1988

AREA OF MAP

MAP 1—EPICENTERS, YEAR OF OCCURRENCE, AND MAGNITUDE

Fault locations from R. L. Christiansen (written communication, 1980, 1988) and U. S. Geological Survey, 1972.

Figure 2.-Earthquake focal mechanisms; lower hemisphere projection, dots indicate compressions, circles indicate dilatations. T and P indicate tension and compression axis. Mechanism numbers correspond to numbered circles on map.

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Wyss, M., and Brune, J. N., 1968, Seismic moment, stress, and source dimensions for earthquakes in the California-Nevada region. Jour. Geoph. Res., v. 73, no. 14, p. 4681-4694.

111°

110°

45°

Approximate boundary of Yellowstone National Park

MONTANA

WYOMING

A

B'

C'

D'

E'

F'

Hebgen Lake

Hebgen Lake earthquake

B

C

D

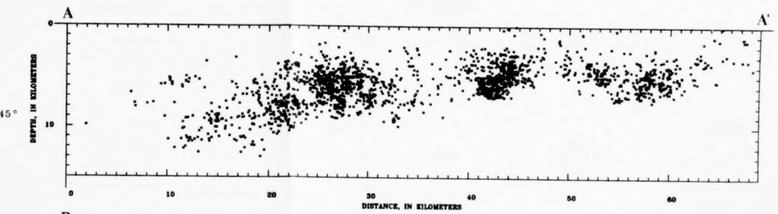
E

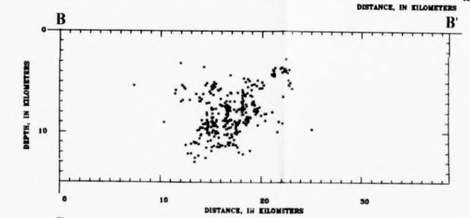
F

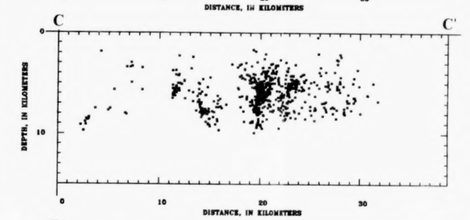
Yellowstone Lake

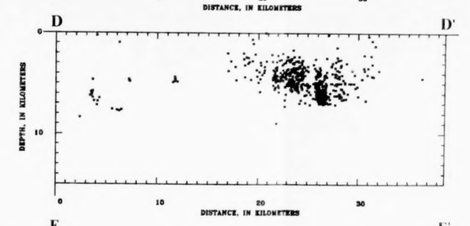
IDAHO

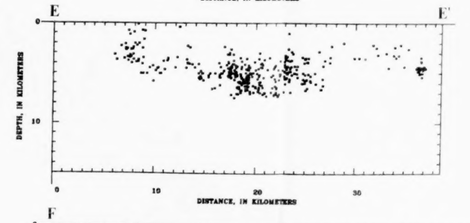
WYOMING

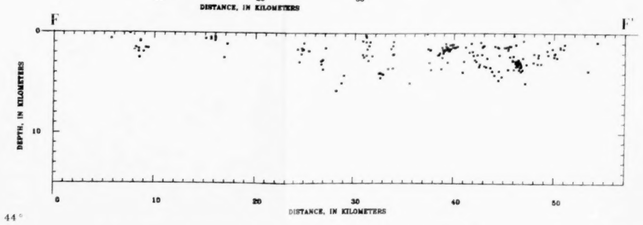












Earthquakes with epicentral uncertainties of 1 kilometer and focal depth uncertainties of 2 kilometers are projected onto a vertical plane in section. See map 2 for area of projections.

EXPLANATION FOR MAP 2

of location
meter epicenter uncertainty
meter epicenter uncertainty
meter epicenter uncertainty
meter epicenter uncertainty
epth known in operation two or more years
dotted where concealed) showing evidence of Quaternary movement
Caldera boundary (ball)
rectangles A-A', B-B',) show area of projection into sections

111°

110°

44°

SCALE 1:250 000

5 0 5 10 15 20 MILES

5 0 5 10 15 20 25 30 KILOMETERS

APPROXIMATE MEAN DECLINATION, 1988

AREA OF MAP

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Fault locations from R. L. Christiansen (written communication, 1980, 1988) and U. S. Geological Survey, 1972.

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DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

MAP SHOWING EARTHQUAKE EPICENTERS (1964—81) IN YELLOWSTONE NATIONAL PARK AND VICINITY, WYOMING, IDAHO, AND MONTANA

By A.M. Pitt

MISCELLANEOUS FIELD STUDIES MAP
Published by the U.S. Geological Survey, 1989

PITT—EARTHQUAKE EPICENTERS (1964—81) YELLOWSTONE NATIONAL PARK, WYOMING, IDAHO, MONTANA 1:250,000 MAP MF—2022